EDGEWOOD

CHEMICAL BIOLOGICAL CENTER

U.S. ARMY SOLDIER AND BIOLOGICAL CHEMICAL COMMAND

ECBC-TR- 296

TEST RESULTS OF PHASE 3 LEVEL B SUITS TO CHALLENGE BY CHEMICAL AND BIOLOGICAL WARFARE AGENTS AND SIMULANTS: SUMMARY REPORT

Robert S. Lindsay
Suzanne A. Procell
Frederick C. Baldauf

RESEARCH AND TECHNOLOGY DIRECTORATE

Alex G. Pappas

ENGINEERING DIRECTORATE

June 2003

2003 1001 096

Aberdeen Proving Ground, MD 21010-5424

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE 2003 June	3. REPORT TYPE AND DATES COVERED Final; 00 Apr – 00 Sep	

4. TITLE AND SUBTITLE Test Results of Phase 3 Level B Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report	5. FUNDING NUMBERS None
6. AUTHOR (S) Lindsay, Robert S.; Procell, Suzanne A.; Baldauf, Frederick C.; and Pappas, Alex G.	

7. PERFORMING ORGANIZATION NAME (S) AND ADDRESS (ES) DIR, ECBC, ATTN: AMSSB-RRT-CE/AMSSB-REN-SN, APG, MD 21010-5424	8. PERFORMING ORGANIZATION REPORT NUMBER ECBC-TR- 296
9. SPONSORING/MONITORING AGENCY NAME (S) AND ADDRESS (ES) DIR, ECBC, ATTN: AMSSB-REN-HD, APG, MD 21010-5424	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

13. ABSTRACT *(Maximum 200 words)*
Swatches from three commercially available Level B protective suits were challenged with liquid droplets of Sarin (GB) and mustard (HD) using modifications of the static diffusion procedure described in TOP 8-2-501. The cumulative mass of each agent that permeated each swatch was determined over time, and the results for all swatches were used to determine a weighted-average cumulative mass for each suit. From these data, a physiologically-derived breakthrough time was calculated for each suit for the purposes of comparison. In addition, intact suits were challenged with corn-oil aerosol to simulate a biological or chemical aerosol. Protection factors were determined for each suit.

14. SUBJECT TERMS			15. NUMBER OF PAGES **40**
HD Swatch testing	Permeation testing		
GB Aerosol testing	Chemical protective suits		16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT **UNCLASSIFIED**	18. SECURITY CLASSIFICATION OF THIS PAGE **UNCLASSIFIED**	19. SECURITY CLASSIFICATION OF ABSTRACT **UNCLASSIFIED**	20. LIMITATION OF ABSTRACT **UL**

Blank

EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, three Occupational Safety and Health Administration Level B* suit designs were tested to assess their capability to protect in a chemical warfare (CW) agent or biological agent environment. Swatches of material from each suit design were tested for resistance to permeation by Sarin (GB) and mustard (HD). From these data, the authors calculated the estimated time it would take to permeate the suit with sufficient agent to cause physiological effects in a person wearing the suit. Each suit design was also tested for its protection factor in an aerosol environment (aerosolized corn oil, which may be representative of a chemical or biological agent, was used). Protection factor is defined as the ratio between the challenge concentration outside the suit and the measured concentration inside the suit. The tests are described, and the calculated physiologically-derived breakthrough times and protection factors (PF) are presented.

---

* Level B protection consists of chemical-resistant clothing (overalls and long-sleeved jacket; hooded one or two piece chemical splash suit; disposable chemical-resistant one-piece suit), inner and outer gloves, chemical-resistant safety boots and hardhat with pressure-demand full-facepiece SCBA or pressure-demand supplied-air respirator with escape SCBA. Level B, rather than Level A, protection is used when a high level of respiratory protection is required but less skin protection is needed.

Blank

PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. This work was started in April 2000 and completed in September 2000.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Service.

Blank

CONTENTS

TABLES

FIGURES

TEST RESULTS OF PHASE 3 LEVEL B SUITS TO CHALLENGE BY CHEMICAL AND BIOLOGICAL WARFARE AGENTS AND SIMULANTS: SUMMARY REPORT

1.   INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance emergency and hazardous material response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, people who are responding to an incident will use personal protective equipment to protect them from exposure to chemical agents or biological agents. The specific personal protective equipment (PPE) that will be used depends upon the situation that they encounter and what they have on hand. In some cases, Level B protective suits may be required to enter a contaminated or potentially contaminated area. Level B suits are chemical-resistant clothing that protect the wearer from liquid chemicals. Air is supplied by a pressure-demand full-facepiece self-contained breathing apparatus (SCBA) or pressure-demand supplied-air respirator with escape SCBA.

2.   OBJECTIVES

This study evaluated three different common and commercially available Level B suits. These three different suits met the Occupational Safety and Health Administration (OSHA) description of Level B as defined in 29 Code of Federal Regulations (CFR) 1910.120, Appendix B. These suits were evaluated to assess how well they resist vapor permeation[1] from liquid contamination by chemical agents Sarin (GB) and mustard (HD) and droplet penetration by a corn-oil aerosol from 0.4 to 0.6 microns in diameter (used to simulate the 0.4 to 5 micron military standard for the possible biological or chemical particulate threat). This information is intended for emergency responders as an aid in evaluating Level B suits when they choose to include military chemical and biological agent protection as a criterion. The information supplements data and information provided by the suits' manufacturers. The suits are tested in new, as-received condition. The effects of aging, temperature extremes, laundering, and other factors are beyond the intended scope of this test program. These tests are conducted to assess percutaneous protection[2] only.

3.   TESTING AND DATA ANALYSIS

3.1   Testing Overview.

The Level B suits that were tested in this test program are listed in Table 1.

---

[1] Throughout this report the term permeation is used even though for some of the tests the precise mechanism of agent transfer is not determined and penetration is likely to be involved also.

[2] Inhalation and ocular protection are typically provided by the use of a SCBA or air-supplied respirator that covers the eyes, nose and mouth.

Table 1. Level B Suits Tested

Model	Manufacturer	Address
Lakeland Coverall, Style 94165	Lakeland Industries, Inc.	Somerville, AL
Mar Mac Coverall, Model 94124	Mar Mac Manufacturing, Inc.	McBee, SC
Mar Mac Coverall, Model 100124	Mar Mac Manufacturing, Inc.	McBee, SC

Tests included the measurement of permeation of both GB and HD through material swatches. Tests were also conducted to measure the total aerosol leakage into the suits through seams, seals, etc., when worn as part of a complete PPE system.

3.2   Liquid Challenge/Vapor Permeation Testing (Agent Swatch Testing).

3.2.1   Liquid Challenge/Vapor Permeation Testing Procedures.

This testing was conducted to measure the actual permeation of chemical agents GB and HD through suit swatches over a 24-hour period. The test was intended to assess how well the suit materials and seams resist agent permeation. For each suit design, all swatches were taken from a single suit. The amount of agent applied and duration of exposure do not represent any particular threat that responders may encounter, but they do serve as a common point of reference for all test results.

The test methodology was taken from TOP 8-2-501[3] and is described in Appendix A. Three swatches were taken from each of six different areas of the suit – 18 total swatches per suit design for GB and 18 more for HD. Swatches were taken from silicone rubber (M45 mask formulation) slabs[4]. For each test six swatches taken from a suit and one silicone swatch were placed in test cells, one swatch per test cell. Laboratory personnel applied a predetermined liquid agent challenge (10 g/m^2) to the top surface of each swatch. Agent droplets were applied to the surface of the first swatch at time zero. Agent was then applied to the surface of each succeeding swatch at 3-minute intervals. The upper chamber of each test cell was sealed. A 1.0 L/min flow of air, from the test cabinet, was maintained in the lower test cell chamber beneath each swatch.

During the 24-hour test period, gas samples were taken on a sequential basis by a laboratory MINICAMS™ (OI Analytical, CMS Field Products Group, Birmingham, AL) with stream selection system (a miniaturized gas chromatograph with flame photometric detector and sampling system) from the air stream beneath each swatch. Gas sampling by the MINICAMS™ began for the first swatch approximately 3 minutes following agent application. Subsequent 3-minute cycles of the MINICAMS™ were composed of 2 minutes of desorption of collected agent vapor from the pre-concentrator tube (PCT) onto the GC column followed by 1 minute of gas sampling (collection of agent vapor in the PCT). Sampling was done sequentially through six

---

[3] Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing). U.S. Army Dugway Proving Ground, UT 3 March 1997, UNCLASSIFIED Report (AD A322329).

[4] Originally, it was intended to use silicone swatches as references or controls, but it was soon found that permeation through the silicone varies too widely for it to be used for that purpose. Silicone swatches were used anyway, because they serve as a reliable source of agent vapor to assure the tester that the MINICAMS™ is responding properly during tests when little or no agent permeates the actual test swatches.

swatches (three from one sampling area followed by three from a second sampling area), the silicone swatch, and then three blank gas samples were taken from the test chamber to purge the sampling line before repeating the sampling sequence. The six swatches, the indicator swatch, and three blanks were all sampled for the first time within the first 30 minutes of the test. Then the sampling sequence began anew.

The MINICAMS™ first determined the amount of agent vapor in each gas sample. Using this result, the amount (ng) of agent vapor present in the air stream that passed beneath the swatch over the time from one gas sample to the next was determined by the MINICAMS™ permeation software. This amount of agent vapor is presumed to be the amount of agent vapor that has permeated the swatch over that time interval. Given the area of the test swatch, the MINICAMS™ permeation software determines the M_f at each elapsed time for each swatch, where the cumulative mass of agent permeating the swatch per unit area at any elapsed time during the 24-hour test is defined as M_f.

3.2.2 Liquid Challenge/Vapor Permeation Testing Analysis.

Each suit yielded M_f data for 18 swatches for each of the two agents over the 24-hour test period. The M_f data are taken for each of the three swatches from one sampling area tested with one of the agents. For this report, the average (of three swatches) cumulative permeation (M_f) for each suit area (for example, gloves) is calculated. This average is then presented, at each of the reported elapsed times, as representative of the suit's permeation resistance at that sampling area. The reported elapsed time for each sampling area is the sum of the elapsed times for the three swatches divided by three. For each suit tested, swatches were taken from a single suit.

To estimate M_f at each elapsed time for a suit, the simplifying assumption is that the exposure is uniform over the entire suit. This permits the use of the weighting factor scheme developed by Belmonte[5] to determine the weighted average M_f over the entire suit at each average elapsed time. The average elapsed time is the sum of the reported elapsed times for all the sampling areas divided by the number of sampling areas. The weighting factors shown in Table 2 were assigned roughly on the basis of surface area assigning a minimum assigned value of 5%. Swatches were not necessarily taken from exactly the same locations for all suits because the suit configurations differed. Note that not all suits have the same components. The weighted average M_f at any average elapsed time is calculated using an equation similar to the following (using the Lakeland 94165 suit weighting factors in Table 2 for this example):

Weighted average M_f = 0.3(suit chest material M_f) + 0.3(suit leg material M_f) + 0.15(suit arm seam M_f) + 0.15(hood seam M_f) + 0.05(boot seam M_f) + 0.05(zipper seam M_f)

---

[5] Belmonte, R.B., *Test Results of Level A Suits to Challenge by Chemical and Biological Warfare Agents and Simulants: Summary Report*, ERDEC-TR-513, U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD, August 1998, UNCLASSIFIED Report (AD A353013).

Table 2. Weighting Factors For Each Sampling Area by Suit

Suit Model	Suit Chest Material	Suit Leg Material	Suit Arm Seam	Crotch Area	Boot Seam	Hood Seam	Hood Material	Zipper Seam
Lakeland Coverall, Style 94165	30	30	15	-	5	15	-	5
Mar Mac Coverall, Model 94124	-	50	15	15	5	-	10	5
Mar Mac Coverall, Model 100124	-	50	15	10	5	-	15	5

3.2.3   Relationship Between Liquid Challenge/Vapor Permeation Test Results and Skin Exposure.

The permeation test is designed to distinguish among these material swatches according to their permeation resistance to chemical agents. It is not intended to specifically replicate threat scenarios that may be encountered in actual use. As previously reported by Belmonte[5], it is instructive to estimate the agent dosage ($C_i t_{skin}$) that would result from such a standard agent challenge as a relative indication of possible physiological effects. This is done by converting the weighted average M_fs to equivalent agent dosages. This relationship was developed by Fedele (written communication, Dr. P. Fedele, R&T Directorate, ERDEC, July 1997) and was reported by Belmonte[5]. For suit materials impermeable to airflow, the equation is:

$$\text{Agent Dosage (mg - min/m}^3) = \frac{M_f \ (\text{ng/cm}^2)}{P_s, \text{ Permeability of skin to agent vapor (cm/min)}}$$

where skin permeability (P_s) is 2 cm/min for HD and 0.1 cm/min for GB. The agent dosage can then be compared to doses that are known to cause certain levels of toxicity. Skin permeability is assumed to be constant over all regions of the body.

3.2.4   Evaluation Criteria for Liquid Challenge/Vapor Permeation Test Results.

When analyzing the test results, it is useful to determine whether the data indicate that the Level B suit provided percutaneous (i.e., skin) protection over some period of time. Mustard vapor can produce erythema (reddening of the skin, certain body regions) at dosages of approximately 100 mg-min/m^3, and can produce vesication (skin burns and blisters, certain body regions) at 200 mg-min/m^3. Sarin vapor can produce incapacitation (twitching, convulsions or loss of consciousness) at unprotected, percutaneous dosages of approximately 8000 mg-min/m^3 and can be lethal at unprotected, percutaneous dosages of 15000 mg-min/m^3 where exposed persons are healthy, young, fit, and well-nourished males of approximately 70-kg mass. People,

12

who are smaller, less fit, etc., may exhibit adverse effects at lower doses ($C_i t_{skin}$). The conservative simplifying assumptions were that the suit would be exposed to a uniform liquid GB challenge over its entire surface, and that this would result in a uniform exposure of all body regions to GB vapor. This is conservative because the areas likely to receive more exposure (hands, arms, chest, back) would also be those less sensitive. Therefore, the amount of agent per unit area (weighted average M_f) necessary to permeate the suit to produce a predetermined physiological effect was estimated by using each of the above dosages and the appropriate skin permeability (P_s). These values are used in the graphs of weighted average M_f versus time given in Appendixes C through F and summarized in Table 3. The breakthrough dosages are assumed to be the HD dosage that produces erythema (100 mg-min/m^3) and the GB dosage that produces incapacitation (8000 mg-min/m^3). A physiologically-derived breakthrough time is the time when the weighted average M_f equals the breakthrough M_f criterion.

Table 3. Agent Breakthrough Criteria

Agent	Breakthrough Dosage (mg-min/m^3)[a]	Physiological Effect	Skin Permeability (P_s), (cm/min)	Breakthrough M_f, (ng/cm^2)[a]
HD	100	Erythema	2	200
HD	200	Vesication	2	400
GB	8000	Incapacitation	0.1	800
GB	15000	Lethality	0.1	1500

[a] These breakthrough criteria are not to be construed as safe threshold values; they are being used only to rank suits.

3.3   System Test (Aerosol Simulant).

3.3.1   Aerosol Simulant Test Procedures.

The testing was conducted to determine leakage of a challenge corn-oil aerosol (physical simulant of a biological or chemical agent aerosol) into a suit ensemble while people of different sizes are wearing appropriately sized ensembles. Volunteers dressed in Level B suits with SCBA entered a chamber with aerosol simulant and performed a standardized series of exercises. Instrumentation measured any aerosol leakage (presumed to be penetration) into the suit through gaps between ensemble components. During the test, the people in the suits performed standardized movements. A brief description of the test and movements made by the people during the test are given in Appendix B. Three different ensembles, listed in Table 1, were tested. Eight suits of each design were worn by 12 volunteers on each of two days, for a total of 24 trials for each suit design. However, because it was not possible to retain the same 12 volunteers throughout the entire course of testing, this variable (the differences among wearers) was not held constant across all suit designs.

From this test a protection factor (PF) was derived. In simplest terms, PF is a measure of the challenge concentration outside the suit divided by the concentration inside the suit ensemble. For example, if the concentration of aerosol inside the suit ensemble is found to be 1/10th the value of the average concentration outside the suit ensemble, the PF is equal to 10.

3.3.2   <u>Aerosol Simulant Analysis</u>.

Samples of aerosol were taken continuously at the neck area and upper arm within the suit and their concentrations were measured by laser photometry, recorded in a computer file and displayed continuously on a computer monitor. These sampling locations were selected as being the most likely locations for aerosol leakage to occur (Leakage usually occurs near openings such as the neck, visor, zipper or outlet valve openings). This is thought to be the worst case and the PF is a worst case PF.

The PF data are presented based upon predetermined PF pass levels, ranging from 2 to 100,000 (i.e., at each pass level the number of failing and passing suits is recorded). The higher the percentage of test occasions that passes at a given PF, the greater the probability that the suit will provide that level of protection in use.

ACRONYMS and ABBREVIATIONS

CFR	Code of Federal Regulations
Ct	Vapor exposure, product of vapor concentration (mg/m^3) and time (minutes)
Ct_{skin}	Vapor exposure to skin
cm^2	Square centimeters
°F	Temperature in degrees Fahrenheit
delta p	Differential pressure
DoD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
ERDEC	U.S. Army Edgewood Research, Development and Engineering Center
g	Gram
GB	Sarin, Isopropylmethylphosphonofluoridate
GC	Gas chromatograph
HD	Sulfur Mustard; 2,2'-Dichlorodiethylsulfide
kg	Kilograms
L	Liter
M_f	Cumulative mass permeation through the fabric
m^2	Square meters
m^3	Cubic meters
mg	Milligram
μL	Microliter
ng	Nanogram
NBC	Nuclear, Biological and Chemical
OSHA	Occupational Safety and Health Administration
PCT	Pre-concentrator tube
PF	Protection Factor
PPE	Personal Protective Equipment
P_s	Skin permeability
RH	Relative Humidity
SCBA	Self-Contained Breathing Apparatus
TOP	Test Operations Procedure

Blank

Appendix A

Modified Static Diffusion Test Procedure

MODIFIED STATIC DIFFUSION TEST

This test procedure was adapted from Test Operations Procedure (TOP) 8-2-501, Permeation and Penetration of Air-Permeable, Semipermeable and Impermeable Materials with Chemical Agents or Simulants (Swatch Testing), U.S. Army Dugway Proving Ground, UT, 3 March 1997, UNCLASSIFIED Report (AD A322329). The test procedure was entitled "Semipermeable and Impermeable Materials Static Diffusion Penetration Testing (Liquid Agent Challenge/Vapor Penetration; delta p = 0, Single Flow Test)". The following procedure was used:

1. Upon receipt of a suit, all available information concerning the suit will be recorded; date of manufacture, lot number, serial number, materials of construction, etc.

2. From each suit, three each 1 and 15/16-in diameter material swatches will be taken for mustard (HD) and a like number taken for Sarin (GB). Depending upon the suit configuration, 3 seam swatches (same diameter) will be taken plus 3 swatches of other flat components such as visor, gloves, suit/visor interface and zipper/material interface for HD and an equal number for GB. Each swatch will be placed in an airtight bag and given a unique serial number, which will be placed on the bag. A list of serial numbers will be kept with the swatches. Alternatively, the swatches for each day's test will be cut from the suit and placed in the environmental chamber for conditioning. Sample identification will accompany each swatch.

3. The environmental chamber will be controlled at a temperature of 90 +/- 2 °F, and the maximum achievable relative humidity (RH) without occurrence of condensation (normally 50% +/- 10% RH). The temperature and RH readings will be checked weekly with a calibrated meter. The test cell air will be drawn from the chamber air. The TOP 8-2-501 specifies that a system control and data acquisition system will be used, but this system will not be used due to budget constraints. The temperature and RH will be recorded in a computer file. Flow rates will be manually recorded. The TOP 8-2-501 specifies that differential pressure monitoring will be done but differential pressure gages will not be used due to budget constraints.

4. The TOP test cell will be used. When assembling, the cell lugs will be tightened by hand to finger tight. The flow rate beneath each swatch will be 1 L/min, which will be controlled by a linear mass flow controller. The flows will be checked with a calibrated test meter weekly. Each test cell will be checked for leaks after assembly by connecting it to the vacuum source and checking that the inlet flow is the same as the outlet flow on the mass flow controller. If the flows don't match, the test cell will be disassembled, adjustments made, the test cell reassembled and flows rechecked.

5. The TOP 8-2-501 specifies that positive control and negative control swatches will be used, but they will not be used due to budgetary and schedule limitations. The swatches will be preconditioned for at least 2 hr and will be monitored by MINICAMS™ for at least one cycle prior to agent application. Eighty-mil silicone will be used, one for each test (six suit swatches and one silicone swatch).

6. Agents GB and HD will be used. The contamination density will be 10 g/m^2 (8 each 1 µL HD droplets or 10 each 1 µL GB droplets). A robotic agent application system is not available. The agent will be applied using the click/touch method with a repeating dispenser.

7. Seven swatches will be tested at once. MINICAMS™ with stream selection system will monitor vapor penetration with a 3-min cycle. There will be three sampling intervals following the silicone during which chamber air will be sampled. Each swatch will be sampled once every 30 min. The MINICAMS™ will be standardized weekly with a range of agent standards (diluted in isopropanol); concentrations will normally range from 1 ng/µL to 100 ng/µL.

8. The test length will be 24 hr.

9. The test cells will be aerated and o-rings replaced between uses. No other cleaning method will be used.

10. The data to be reported are cumulative permeation (ng/cm^2) at various elapsed times (minutes) for each swatch. The elapsed time for each swatch is the time from agent contamination. All recorded data will be placed in laboratory notebooks and one technical report per suit will be drafted at the conclusion of this effort.

Appendix B

Aerosol Simulant Test Procedure

To properly test suits with statistical significance, eight suit ensembles of each model are provided to the Mask Fit Test Facility for examination. Each ensemble is new and inspected as received. The suit ensembles include relevant accessory equipment such as respirators that are worn with the suits, gloves, boots, and any other equipment that is necessary for chemical agent use. The suit ensembles are run on at least 10 different subjects with at least 22 trials. The eight suits are reused to achieve the 22 or more trials. Sampling of suits is done at the neck and upper arm for each trial.

Exercise routine for all suits is as follows:

Phase 1 (Pre-Operational):

      1) standing still, normal breathing
      2) bending forward and touching toes
      3) jogging in place
      4) raising arms above head and looking upward
      5) bending knees and squatting
      6) crawling on hands and knees
      7) torso twists with hands folded on chest
      8) standing still, normal breathing

Phase 2 (Operational):

      1) climb step ladder
      2) move 3 lb boxes from table to floor
      3) rest
      4) roll walls and ceiling
      5) bag clothes
      6) rest
      7) loosen bolts
      8) move 3 lb boxes from floor to table

The phase 1 (pre-operational) exercises are performed for one min each for a total of eight minutes. The phase 2 (operational) exercises are normally performed for four minutes each for a total of 32 minutes. Hence, the overall total exercise time for the two phases is normally 40 minutes. In this case, however, because of the high leakage rates of the suits, the phase 2 exercises were only performed for one minute each.

Blank

Lakeland Coverall, Style 94165

Figure C - 1. Lakeland Coverall, Style 94165 - Front View

Table C - 1. Lakeland Coverall - Average HD Permeation

Average Cumulative Permeation (ng/cm^2)													
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Seam	Time (min)	Suit Chest Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average M$_f$
5	1	12	1	14	3	4	3	14	1	4	0	9	2
35	33	42	7	44	18	35	36	44	12	33	22	39	26
65	65	72	15	74	30	65	58	74	25	63	81	69	49
95	70	102	25	105	39	96	83	104	29	93	177	99	66
125	77	132	37	135	48	126	109	134	34	123	301	129	85
155	85	162	51	165	57	156	137	164	40	153	451	159	107
185	93	192	68	196	67	187	167	194	46	183	619	189	132
215	105	222	87	226	78	217	200	224	54	213	801	220	159
245	118	252	108	256	89	247	237	254	63	243	996	250	189
275	133	282	131	287	102	278	280	284	73	273	1199	280	222
305	151	312	155	317	117	308	327	314	83	303	1404	310	259
335	171	342	181	347	136	338	378	344	95	333	1606	340	297
365	192	372	209	378	159	369	434	374	106	363	1805	370	338
395	215	402	236	408	187	399	493	404	118	393	1998	400	381
425	238	432	262	438	219	429	554	434	130	423	2186	430	425
455	261	462	289	469	258	460	616	464	142	453	2376	460	471
485	285	492	316	499	305	490	681	494	155	483	2561	491	519
515	308	522	342	529	359	520	746	524	168	513	2743	521	567
545	332	552	368	560	422	551	812	554	182	543	2922	551	617
575	357	582	393	590	494	581	879	584	195	573	3099	581	669
605	382	612	419	620	573	611	946	614	208	603	3277	611	721
635	406	642	445	651	658	642	1013	644	221	633	3454	641	775
665	431	672	470	681	747	672	1080	674	234	663	3628	671	829
695	455	702	495	711	843	702	1147	704	247	693	3800	701	883
725	478	732	520	742	944	733	1214	734	260	723	3971	731	939
755	502	762	545	772	1049	763	1283	764	272	753	4140	762	995
785	526	792	570	802	1158	793	1351	794	285	783	4308	792	1052
815	549	822	594	833	1275	824	1426	824	298	813	4474	822	1111
845	572	853	618	863	1400	854	1506	854	310	844	4638	852	1174
875	594	883	642	893	1531	884	1584	884	322	874	4802	882	1236
905	616	913	666	924	1666	915	1661	914	334	904	4966	912	1298
935	638	944	689	954	1804	945	1739	944	346	935	5129	943	1361
965	660	974	711	984	1945	975	1820	974	358	965	5290	973	1425
995	681	1004	733	1015	2088	1006	1905	1004	370	995	5451	1003	1490
1025	702	1035	755	1045	2234	1036	1994	1034	381	1026	5610	1033	1557
1055	722	1065	778	1075	2378	1066	2085	1064	393	1056	5768	1064	1624
1085	742	1095	800	1106	2517	1097	2179	1094	405	1086	5928	1094	1690
1115	760	1126	821	1136	2654	1127	2274	1124	416	1117	6086	1124	1757
1145	778	1156	842	1166	2789	1157	2370	1154	426	1147	6243	1154	1823
1175	796	1186	863	1197	2916	1188	2466	1184	437	1177	6400	1184	1887
1205	814	1217	884	1227	3037	1218	2560	1214	447	1208	6556	1215	1950
1235	830	1247	904	1257	3151	1248	2652	1244	457	1238	6708	1245	2011
		1277	924	1288	3258	1279	2743			1268	6856		
		1308	943	1318	3360	1309	2832			1299	7000		
		1338	962	1348	3458	1339	2922			1329	7141		
		1368	981	1379	3551	1370	3012			1359	7282		
		1399	999	1409	3639	1400	3102			1390	7421		
		1429	1017			1430	3189			1420	7556		

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M$_f$ = 0.3(suit chest material M$_f$) + 0.3(suit leg material M$_f$) + 0.15(suit arm seam M$_f$) + 0.15(hood seam M$_f$) + 0.05(boot seam M$_f$) + 0.05(zipper seam M$_f$)

Table C - 2. Lakeland Coverall - Average GB Permeation

Average Cumulative Permeation (ng/cm^2)													
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Seam	Time (min)	Suit Chest Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average M$_i$
13	0	5	0	4	1	12	1	4	0	14	0	9	1
43	8	35	964	33	10	42	13	34	4	44	1699	39	238
73	18	65	2871	63	27	72	27	64	11	74	5107	69	704
104	24	95	4666	93	47	102	35	95	16	104	8368	99	1144
134	27	125	6305	123	64	132	42	125	21	134	11314	129	1543
164	30	155	7773	153	78	162	49	155	24	164	13944	159	1900
195	32	185	9046	183	90	192	55	186	27	194	16249	189	2210
225	35	215	10142	213	102	222	60	216	32	224	18251	219	2479
255	40	245	11086	243	112	252	65	246	38	254	20001	250	2713
286	45	275	11914	273	121	282	70	277	43	284	21528	280	2919
316	50	305	12651	303	130	312	75	307	48	314	22876	310	3101
346	54	335	13313	333	138	342	80	337	53	344	24077	340	3264
377	56	365	13894	363	145	372	84	368	57	374	25141	370	3408
407	58	395	14411	393	152	402	88	398	60	404	26088	400	3536
437	60	425	14875	423	158	432	92	428	63	434	26938	430	3651
468	61	455	15287	453	164	462	96	459	66	464	27700	460	3753
498	62	485	15664	483	170	492	100	489	68	494	28388	490	3847
528	63	515	16010	513	175	522	104	519	71	524	29012	521	3932
559	64	545	16327	543	179	552	107	550	73	554	29583	551	4010
589	64	575	16619	573	184	582	111	580	75	584	30109	581	4082
619	64	605	16886	603	188	612	114	610	77	614	30598	611	4148
650	65	635	17130	633	191	642	117	641	78	644	31052	641	4209
680	65	665	17360	663	194	672	120	671	79	674	31470	671	4266
710	65	695	17572	693	198	702	122	701	80	704	31859	701	4319
741	65	725	17768	723	200	732	125	732	80	734	32222	731	4368
771	65	755	17956	753	203	762	128	762	81	764	32560	761	4414
801	65	785	18133	783	206	792	130	792	82	794	32873	792	4457
832	65	815	18299	813	208	822	133	823	83	824	33167	822	4498
862	65	845	18455	844	212	853	136	853	84	854	33440	852	4537
892	65	875	18601	874	215	883	140	883	84	884	33698	882	4573
923	65	905	18740	904	218	913	143	914	85	914	33942	912	4608
953	65	935	18873	935	222	944	147	944	86	944	34174	943	4641
983	65	965	18999	965	225	974	150	974	87	974	34394	973	4672
1014	65	995	19119	995	228	1004	153	1005	87	1004	34604	1003	4702
1044	65	1025	19232	1026	230	1035	156	1035	88	1034	34804	1033	4730
1074	65	1055	19341	1056	232	1065	159	1065	89	1064	34994	1063	4757
1105	65	1085	19445	1086	234	1095	162	1096	89	1094	35173	1094	4783
1135	65	1115	19543	1117	236	1126	164	1126	90	1124	35342	1124	4807
1165	65	1145	19639	1147	238	1156	167	1156	91	1154	35503	1154	4831
1196	65	1175	19732	1177	240	1186	169	1187	91	1184	35659	1184	4854
1226	65	1205	19820	1208	241	1217	172	1217	92	1214	35807	1215	4875
1256	65	1235	19904	1238	243	1247	174	1247	93	1244	35949	1245	4896
1287	65	1265	19985	1268	245	1277	177	1278	94	1274	36084	1275	4916
1317	65	1295	20063	1299	246	1308	179	1308	94	1304	36213	1305	4935
1347	65	1325	20137	1329	248	1338	181	1338	95	1334	36336	1335	4953
1378	65	1355	20209	1359	249	1368	184	1369	95	1364	36453	1366	4971
1408	65	1385	20278	1390	251	1399	186	1399	95	1394	36567	1396	4988
		1415	20344	1420	252	1429	188	1429	95	1424	36676	1424	4984

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_f = 0.3(suit chest material M_f) + 0.3(suit leg material M_f) + 0.15(suit arm seam M_f) + 0.15(hood seam M_f) + 0.05(boot seam M_f) + 0.05(zipper seam M_f)
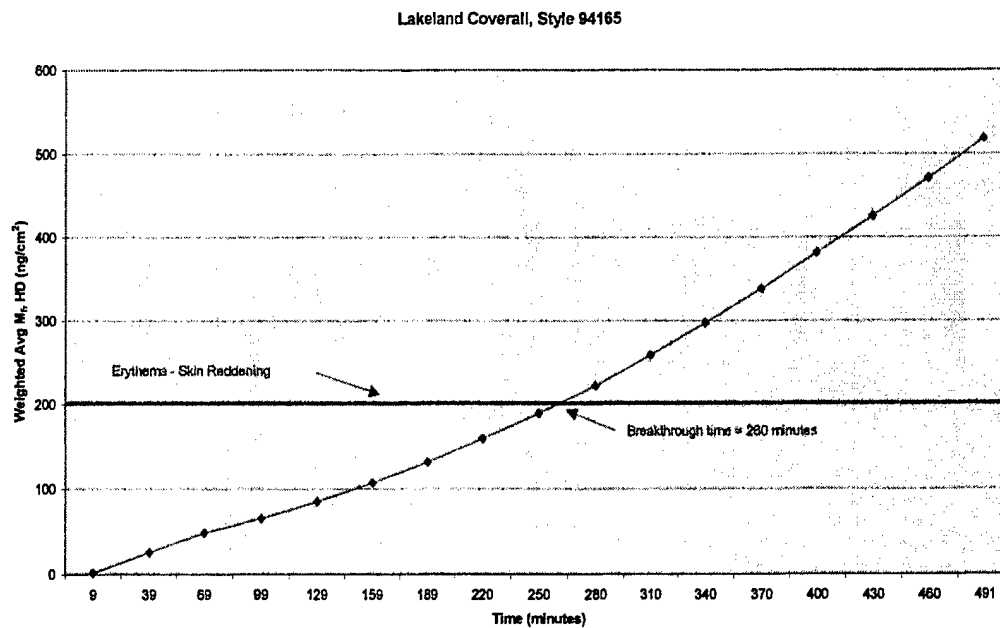
Figure C - 2. Lakeland Coverall - Weighted Average HD Permeation

Figure C - 3. Lakeland Coverall - Weighted Average GB Permeation
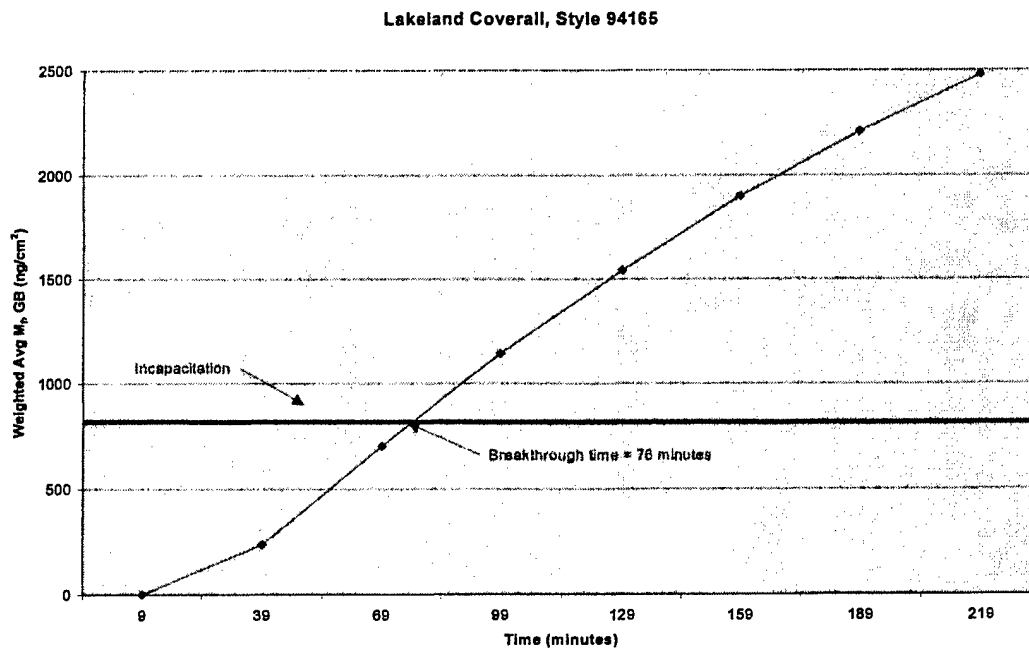
Lakeland Coverall, Style 94165
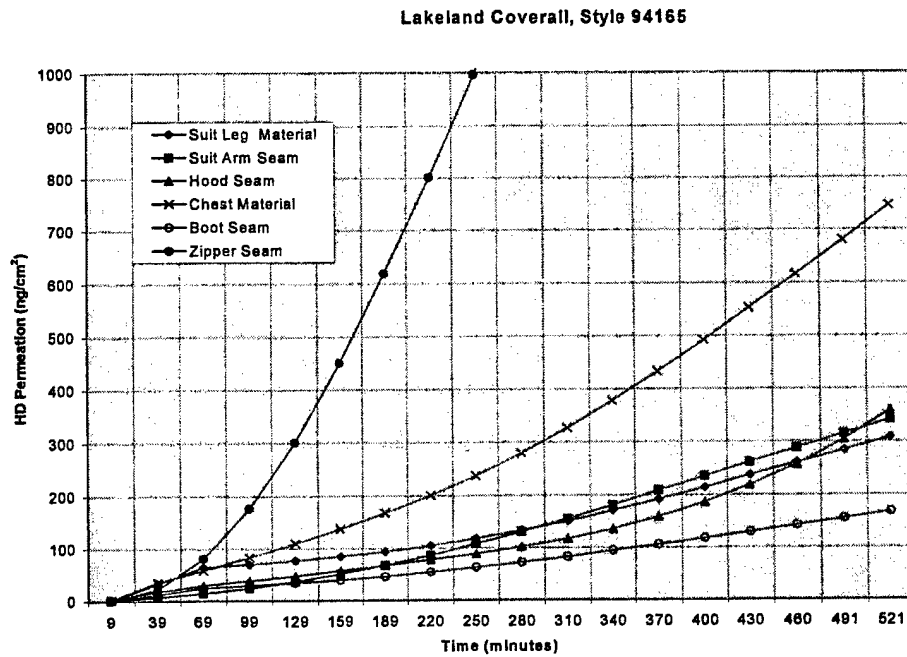
Figure C - 4. Lakeland Coverall - HD Permeation by Sampling Area

Lakeland Coverall, Style 94165
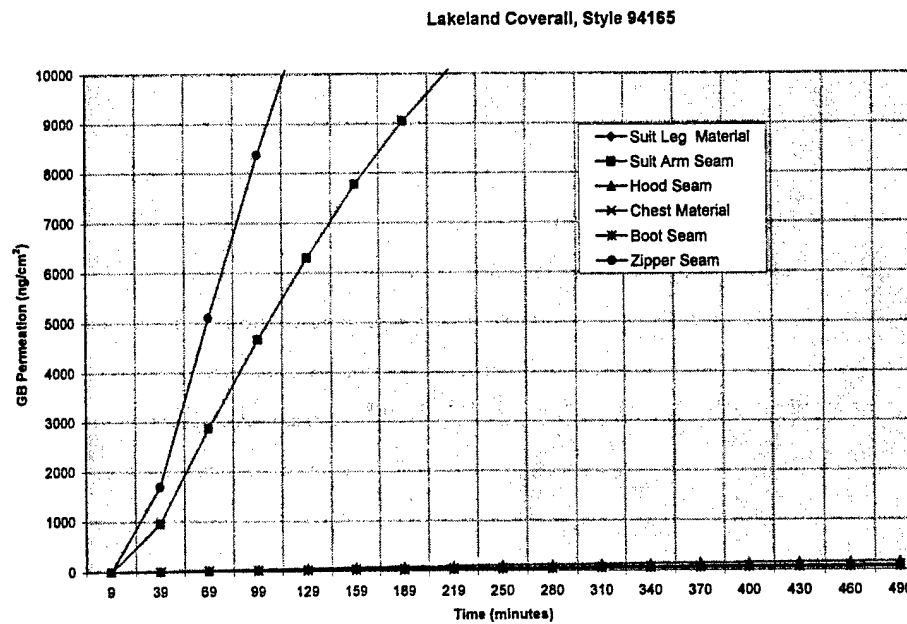
Figure C - 5. Lakeland Coverall - GB Permeation by Sampling Area

Table C - 3. Lakeland Coverall - System Test (Aerosol Simulant) Results

PF	Visor Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	.00	100.00	0	.00	100.00
2	13	54.17	45.83	13	54.17	45.83
5	9	91.67	8.33	9	91.67	8.33
10	2	100.00	.00	2	100.00	.00
50	0	100.00	.00	0	100.00	.00
100	0	100.00	.00	0	100.00	.00
150	0	100.00	.00	0	100.00	.00
500	0	100.00	.00	0	100.00	.00
1000	0	100.00	.00	0	100.00	.00
1667	0	100.00	.00	0	100.00	.00
2000	0	100.00	.00	0	100.00	.00
5000	0	100.00	.00	0	100.00	.00
6667	0	100.00	.00	0	100.00	.00
10000	0	100.00	.00	0	100.00	.00
20000	0	100.00	.00	0	100.00	.00
50000	0	100.00	.00	0	100.00	.00
100000	0	100.00	.00	0	100.00	.00
No. of Trials	24			24		

Table C - 4. Lakeland Coverall - Overall Test Results

Physiologically-derived breakthrough time (minutes)		Aerosol PF Pass Rate (%) at PF Equal to:			Exercise Phase
Incapacitation	Erythema				
GB	HD	2	5	10	
76	260	46	8	0	Pre-Operational
		46	8	0	Operational

Appendix D

Mar Mac Coverall Model 94124

Figure D - 1. Mar Mac 94124 - Front View

Table D - 1. Mar Mac 94124 - Average HD Permeation

Average Cumulative Permeation (ng/cm²)													
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Material	Time (min)	Crotch Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average M_f
12	6	5	4	3	4	13	1	4	0	14	5	8	4
43	24	35	30	34	53	43	4	34	3	44	37	39	25
73	34	65	40	64	64	73	7	64	7	74	98	69	36
104	46	95	48	94	77	104	9	95	10	104	186	99	49
134	57	125	59	125	88	134	12	125	14	134	286	129	63
164	68	155	73	155	101	164	17	155	20	164	395	160	78
195	80	185	88	185	116	195	22	186	28	194	513	190	95
225	93	215	107	216	136	225	28	216	39	224	632	220	114
255	107	245	129	246	159	255	36	246	52	254	752	250	134
286	122	275	156	276	190	286	46	277	68	284	874	280	157
316	138	305	187	307	227	316	56	307	88	314	1002	311	183
346	158	335	223	337	266	346	68	337	111	344	1133	341	212
377	181	365	260	367	307	377	81	368	137	374	1263	371	242
407	203	395	299	398	350	407	95	398	166	404	1400	401	274
437	224	425	338	428	392	437	109	428	196	434	1539	431	305
468	246	455	379	458	434	468	123	459	225	464	1678	462	337
498	269	485	420	489	477	498	137	489	254	494	1822	492	370
528	293	515	461	519	520	528	151	519	283	524	1968	522	403
559	315	545	502	549	564	559	166	550	311	554	2115	552	435
589	336	575	543	580	607	589	180	580	340	584	2264	583	468
619	358	605	584	610	648	619	195	610	370	614	2413	613	500
650	379	635	624	640	689	650	209	640	398	644	2565	643	531
680	400	665	663	671	728	680	223	671	426	674	2722	673	563
710	421	695	702	701	765	710	237	701	453	704	2880	703	594
741	441	725	741	731	802	741	251	731	480	734	3034	734	625
771	460	755	780	762	838	771	265	762	506	764	3189	764	655
801	479	785	818	792	873	801	278	792	530	794	3345	794	685
832	498	815	856	822	906	831	291	822	554	824	3503	824	715
862	517	845	895	853	939	862	304	853	577	854	3666	855	744
892	535	875	932	883	972	892	316	883	600	884	3833	885	773
923	551	905	967	913	1004	922	328	913	623	914	4007	915	802
953	568	935	1002	944	1035	953	341	944	643	944	4187	945	830
983	584	965	1039	974	1066	983	353	974	663	974	4372	975	859
1014	601	995	1076	1004	1096	1013	364	1004	682	1004	4559	1006	888
1044	617	1025	1114	1035	1127	1044	376	1035	701	1034	4749	1036	917
1074	633	1055	1151	1065	1156	1074	386	1065	719	1064	4944	1066	946
1105	649	1085	1186	1095	1183	1104	397	1095	737	1094	5140	1096	974
1135	664	1115	1221	1126	1210	1135	407	1125	755	1124	5333	1126	1002
1165	679	1145	1255	1156	1236	1165	418	1156	771	1154	5526	1157	1029
1196	693	1175	1287	1186	1260	1195	428	1186	788	1184	5716	1187	1055
1226	709	1205	1317	1217	1286	1226	438	1216	804	1214	5902	1217	1082
1256	724	1235	1347	1247	1312	1256	449	1247	820	1244	6088	1247	1108
1287	739	1265	1377	1277	1337	1286	459	1277	836	1274	6275	1278	1134
1317	754	1295	1406	1308	1360	1317	469	1307	851	1304	6461	1308	1160
1347	768	1325	1435	1338	1383	1347	479	1338	865	1334	6646	1338	1185
1378	782	1355	1462	1368	1405	1377	488	1368	879	1364	6831	1368	1210
1408	796	1385	1489	1399	1427	1407	497	1398	893	1394	7014	1398	1234
		1415	1516	1429	1448			1429	908	1424	7198		

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average M_f = 0.5(Suit Matl M_f) + 0.15(Suit Seam M_f) + 0.15(Crotch Matl M_f) + 0.1(Hood Matl M_f) + 0.05(Boot Seam M_f) + 0.05(Zipper Seam M_f).

Table D - 2. Mar Mac 94124 - Average GB Permeation

Average Cumulative Permeation (ng/cm²)													
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Material	Time (min)	Crotch Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average M_t
13	5	5	2	4	2	13	39	4	22	14	3	9	10
43	21	35	18	34	30	44	307	35	1602	44	1503	39	218
73	33	66	39	64	56	74	698	65	4695	75	4473	69	591
103	45	96	64	94	82	104	1139	95	8028	105	7319	100	979
133	58	126	83	124	108	134	1589	125	11386	135	9887	130	1354
163	70	157	100	154	132	165	2025	155	14715	166	12175	160	1712
193	82	187	114	184	155	195	2437	186	17999	196	14230	190	2051
223	95	217	127	214	178	225	2826	216	21207	226	16075	220	2372
253	107	248	139	244	199	255	3192	246	24319	257	17742	251	2676
283	119	278	149	274	220	286	3540	276	27334	287	19229	281	2963
313	130	308	159	304	239	316	3866	307	30245	317	20565	311	3233
343	141	339	169	334	257	346	4170	337	32944	348	21777	341	3483
373	150	369	177	364	274	376	4459	367	35413	378	22874	371	3712
403	160	399	185	394	291	403	4628			408	23873		
433	168	430	192	424	306	431	4711			439	24778		
463	177	460	198	454	321	458	4790			469	25609		
493	186	490	204	484	336	485	4867			499	26383		
523	197	521	209	514	351	512	4943			530	27090		
553	207	551	214	544	365	540	5017			560	27736		
583	216	581	219	574	379	567	5090			590	28335		
613	224	612	224	604	392	594	5162			621	28891		
643	231	642	228	634	404	621	5232			651	29405		
673	238	672	232	664	416	648	5301			681	29879		
703	244	703	236	694	427	676	5368			712	30323		
733	251	733	240	724	437	703	5433			742	30741		
763	257	763	243	754	448	730	5497			772	31134		
793	263	793	247	784	457	757	5561			803	31503		
823	268	824	250	814	466	785	5622			833	31850		
853	273	854	253	844	475	812	5681			863	32177		
883	278	884	256	874	484	839	5737			894	32489		
913	283	915	258	904	492	866	5792			924	32785		
943	287	945	261	934	499	894	5846			954	33065		
973	291	975	264	964	507	921	5900			985	33327		
1003	295	1006	266	994	514	948	5951			1015	33576		
1033	300	1036	269	1024	521	975	6002			1045	33813		
1063	304	1066	271	1054	528	1002	6051			1076	34037		
1093	309	1097	273	1084	535	1030	6099			1106	34248		
1123	313	1127	275	1114	543	1057	6146			1136	34452		
1153	318	1157	278	1144	552	1084	6191			1167	34647		
1183	322	1188	280	1174	560	1111	6237			1197	34834		
1213	326	1218	282	1204	567	1139	6281			1227	35013		
1243	329	1248	284	1234	574	1166	6324			1258	35184		
1273	333	1279	286	1264	581	1193	6366			1288	35352		
1303	336	1309	288	1294	587	1220	6406			1318	35517		
1333	339	1339	290	1324	594	1247	6446			1349	35681		
1363	342	1370	292	1354	600	1275	6485			1379	35841		

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average $M_t = 0.5(\text{Suit Matl } M_t) + 0.15(\text{Suit Seam } M_t) + 0.15(\text{Crotch Matl } M_t) + 0.1(\text{Hood Matl } M_t) + 0.05(\text{Boot Seam } M_t) + 0.05(\text{Zipper Seam } M_t)$.

Note 4: Sampling for boot seam was ended prematurely due to equipment failure.

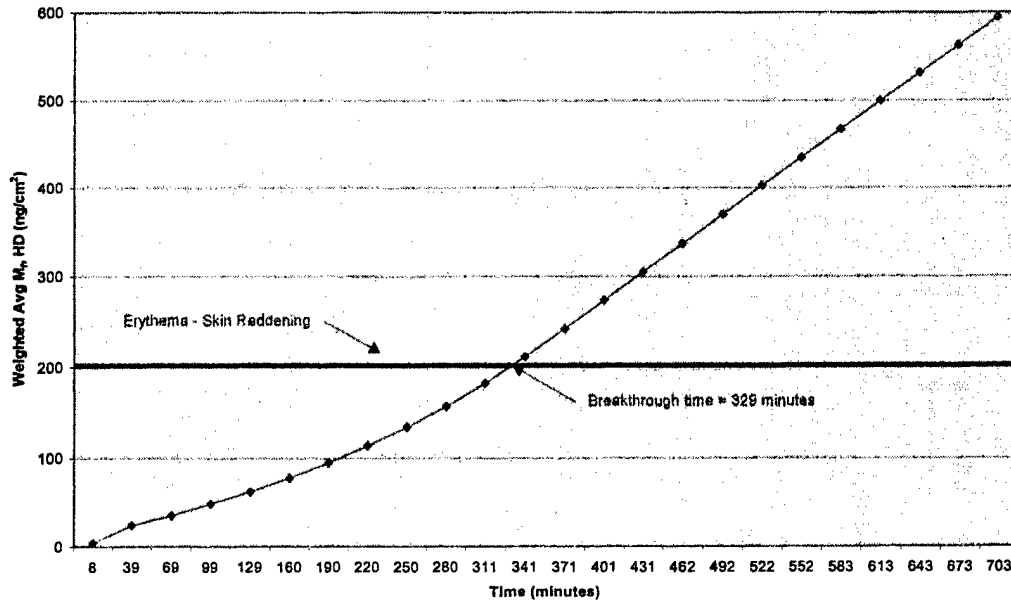**Figure D - 2. Mar Mac 94124 – Weighted Average HD Permeation**
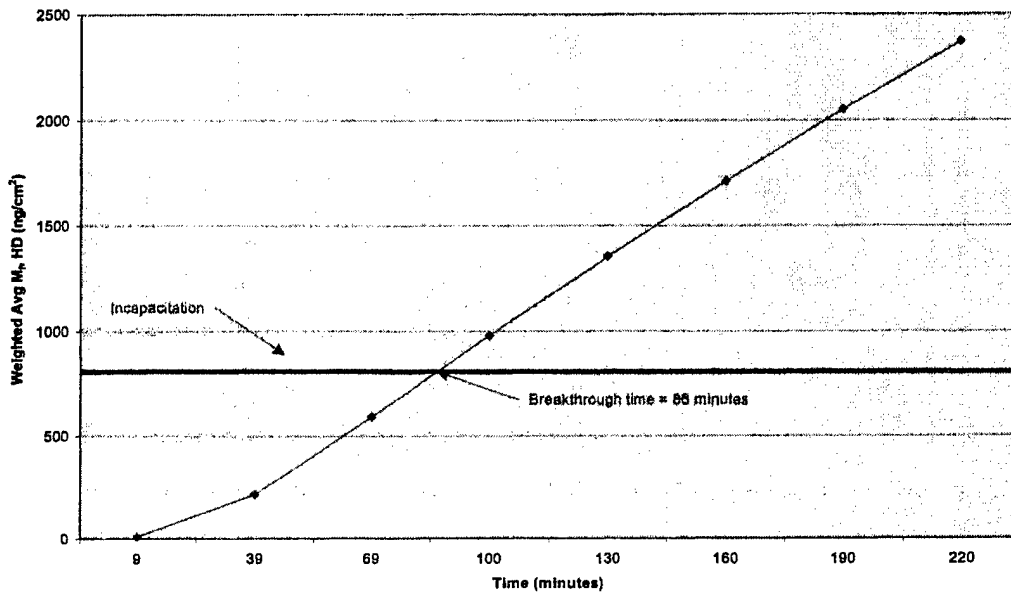
Figure D - 3. Mar Mac 94124 – Weighted Average GB Permeation

MarMac Coverall Model 94124
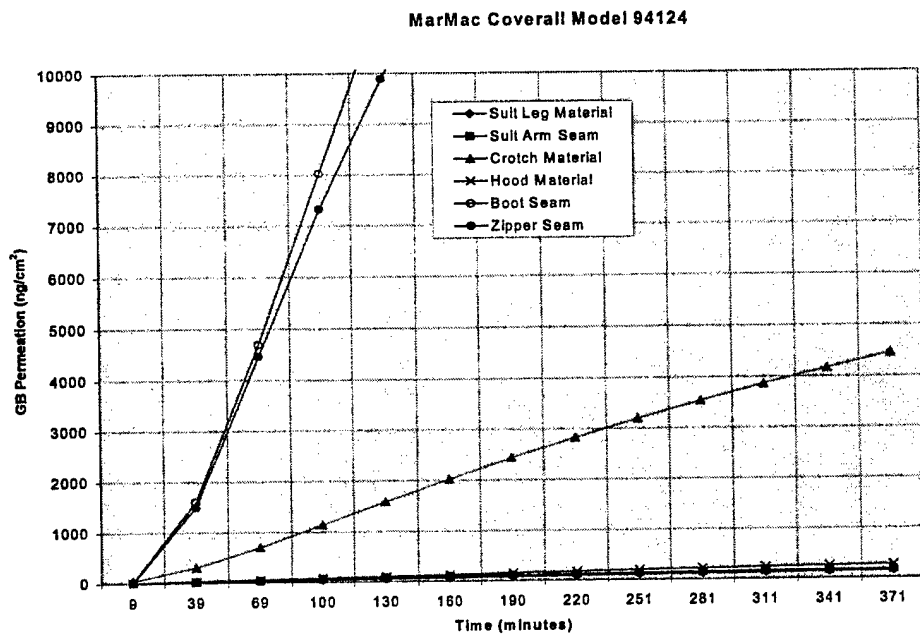
Figure D - 4. Mar Mac 94124 - HD Permeation by Sampling Area

MarMac Coverall Model 94124
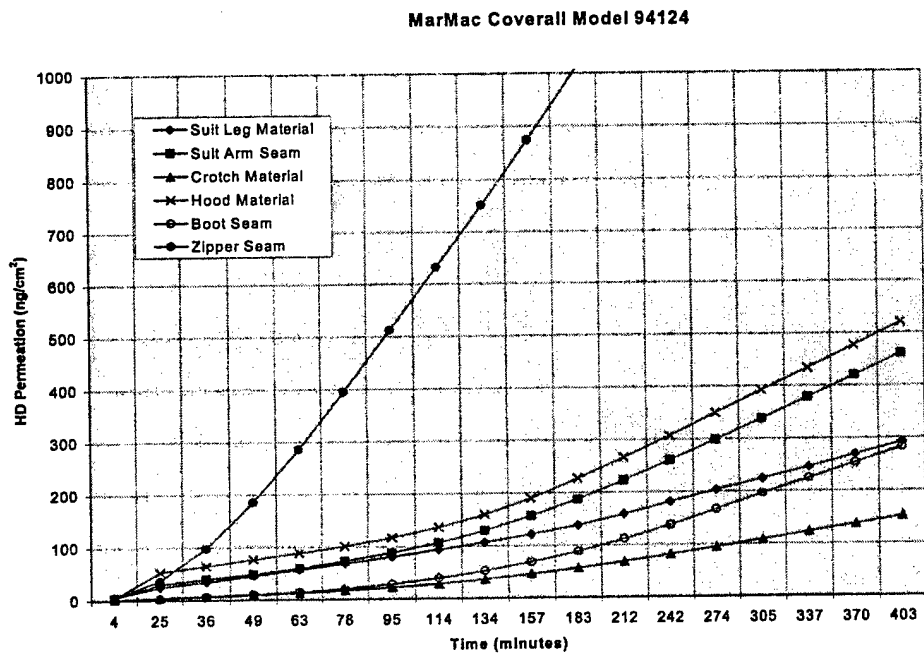
Figure D - 5. Mar Mac 94124 - GB Permeation by Sampling Area.

31

Table D - 3. Mar Mac 94124 - System Test (Aerosol Simulant) Results

PF	Visor Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	.00	100.00	0	.00	100.00
2	12	50.00	50.00	12	50.00	50.00
5	6	75.00	25.00	9	87.50	12.50
10	6	100.00	.00	3	100.00	.00
50	0	100.00	.00	0	100.00	.00
100	0	100.00	.00	0	100.00	.00
150	0	100.00	.00	0	100.00	.00
500	0	100.00	.00	0	100.00	.00
1000	0	100.00	.00	0	100.00	.00
1667	0	100.00	.00	0	100.00	.00
2000	0	100.00	.00	0	100.00	.00
5000	0	100.00	.00	0	100.00	.00
6667	0	100.00	.00	0	100.00	.00
10000	0	100.00	.00	0	100.00	.00
20000	0	100.00	.00	0	100.00	.00
50000	0	100.00	.00	0	100.00	.00
100000	0	100.00	.00	0	100.00	.00
No. of Trials	24			24		

Table D - 4. Mar Mac 94124 - Overall Test Results

Physiologically-derived breakthrough time (minutes)		Aerosol PF Pass Rate (%) at PF Equal to:			Exercise Phase
Incapacitation	Erythema	2	5	10	
GB	HD				
86	329	50	25	0	Pre-Operational
		50	13	0	Operational

Appendix E

Mar Mac Coverall Model 100124

Figure E - 1. Mar Mac 100124 - Front View

Table E - 1. Mar Mac 100124 - Average HD Permeation

				Average Cumulative Permeation (ng/cm²)									
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Material	Time (min)	Crotch Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average M_f
14	1	12	6	4	1	13	9	5	0	3	3	9	3
45	4	42	32	34	28	43	46	36	3	33	59	39	18
75	8	73	49	64	52	73	107	66	5	64	168	69	33
105	11	103	62	95	66	104	254	96	8	94	339	99	55
135	14	133	77	125	80	134	543	126	14	124	555	129	92
165	21	163	94	155	97	164	968	156	27	154	810	160	145
195	30	193	112	185	117	194	1497	186	45	184	1099	190	211
226	42	224	133	215	141	224	2111	217	72	214	1410	220	287
256	57	254	155	246	167	255	2774	247	108	245	1734	250	372
286	75	284	179	276	196	285	3479	277	149	275	2068	280	463
316	95	314	204	306	228	315	4199	307	193	305	2406	311	557
346	119	344	230	336	262	345	4907	337	241	335	2743	341	653
377	143	374	257	366	298	375	5622	367	292	365	3080	371	750
407	167	405	284	396	334	406	6347	398	344	396	3416	401	848
437	192	435	312	427	370	436	7073	428	396	426	3758	431	947
467	217	465	342	457	407	466	7801	458	447	456	4102	461	1046
497	241	495	373	487	444	496	8517	488	496	486	4451	492	1144
527	266	525	404	517	481	526	9218	518	545	516	4807	522	1240
558	290	555	437	547	517	556	9929	549	592	546	5167	552	1338
588	314	586	470	578	552	587	10633	579	637	577	5533	582	1434
618	337	616	504	608	588	617	11309	609	682	607	5906	612	1528
648	359	646	540	638	623	647	11974	639	726	637	6282	643	1620
678	382	676	576	668	657	677	12629	669	766	667	6662	673	1711
709	403	706	612	698	691	707	13269	700	806	697	7048	703	1799
739	424	737	647	729	723	738	13888	730	845	727	7438	733	1885
769	444	767	683	759	756	768	14490	760	883	758	7830	763	1969
799	464	797	718	789	788	798	15082	790	920	788	8219	793	2052
829	483	827	754	819	819	828	15673	820	956	818	8603	824	2134
860	502	857	790	849	850	858	16254	850	992	848	8987	854	2215
890	521	887	826	880	880	889	16817	881	1025	878	9376	884	2293
920	540	918	862	910	910	919	17364	911	1057	909	9768	914	2370
950	557	948	897	940	938	949	17887	941	1089	939	10165	944	2444
980	575	978	933	970	967	979	18401	971	1119	969	10557	975	2517
1010	592	1008	968	1000	994	1009	18917	1001	1149	999	10938	1005	2589
1041	609	1038	1004	1030	1021	1040	19419	1032	1179	1029	11317	1035	2660
1071	625	1068	1039	1061	1049	1070	19908	1062	1207	1059	11688	1065	2730
1101	642	1099	1074	1091	1075	1100	20381	1092	1235	1090	12047	1095	2798
1131	658	1129	1108	1121	1100	1130	20831	1122	1262	1120	12399	1126	2862
1161	673	1159	1142	1151	1125	1160	21273	1152	1288	1150	12741	1156	2926
1192	687	1189	1175	1181	1148	1191	21703	1183	1314	1180	13075	1186	2987
1222	700	1219	1208	1212	1169	1221	22112	1213	1338	1210	13406	1216	3045
1252	713	1250	1240	1242	1190	1251	22512	1243	1363	1240	13730	1246	3102
1282	726	1280	1270	1272	1209	1281	22905	1273	1387	1271	14043	1276	3159
1312	739	1310	1300	1302	1228	1311	23285	1303	1410	1301	14341	1307	3213
1343	752	1340	1328	1333	1248	1342	23658	1333	1433	1331	14628	1337	3266
1373	764	1370	1357	1363	1267	1372	24024	1364	1455	1361	14904	1367	3319
1403	776	1400	1385	1393	1285	1402	24389	1394	1476	1391	15170	1397	3371
1433	787	1431	1412	1423	1303	1432	24751	1424	1498	1422	15431	1427	3422

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average $M_f = 0.5$(Suit Matl M_f) + 0.15(Suit Seam M_f) + 0.15(Hood Matl M_f) + 0.1(Crotch Matl M_f) + 0.05(Boot Seam M_f) + 0.05(Zipper Seam M_f).

Table E - 2. Mar Mac 100124 - Average GB Permeation

Average Cumulative Permeation (ng/cm²)													
Time (min)	Suit Leg Material	Time (min)	Suit Arm Seam	Time (min)	Hood Material	Time (min)	Crotch Material	Time (min)	Boot Seam	Time (min)	Zipper Seam	Average Time (min)	Weighted Average Mf
12	3	15	4	3	1	13	0	4	0	6	2	9	2
42	15	45	251	33	24	43	29	34	252	36	2329	39	66
72	23	75	984	63	37	73	84	64	1235	66	7515	69	238
102	27	105	1902	93	45	103	139	94	2735	96	13315	99	461
132	31	136	2679	123	51	133	193	124	4241	126	19162	129	663
162	34	166	3325	153	56	163	244	154	5657	157	24950	159	839
192	37	196	3866	183	60	193	292	184	6934	187	30611	189	992
222	39	226	4329	213	64	223	337	214	8074	217	36103	219	1127
252	41	256	4735	243	68	253	380	244	9089	247	41302	249	1246
282	43	286	5096	273	71	283	419	274	9973	277	46024	279	1351
312	45	317	5421	303	75	313	457	304	10746	308	50338	309	1445
342	47	347	5716	333	78	343	492	334	11415	338	54379	339	1529
372	49	377	5985	363	81	373	524	364	11996	368	58155	369	1605
402	50	407	6231	393	84	403	554	394	12505	398	61644	400	1673
432	52	437	6456	423	86	433	582	424	12946	428	64886	430	1734
462	54	467	6663	453	88	463	608	454	13331	458	67893	460	1790
492	55	498	6853	483	90	493	632	484	13663	489	70677	490	1839
522	55	525	7004	513	92	523	653	514	13949				
552	56	549	7115	543	93	553	674	544	14200				
582	57	573	7210	573	95	583	692	574	14419				
612	57	597	7301	603	96	613	710	604	14614				
642	57	621	7386	633	98	643	726	634	14787				
672	57	646	7467	663	99	673	741	664	14941				
702	57	670	7542	693	101	703	756	694	15080				
732	57	694	7613	723	102	733	769	724	15204				
762	57	718	7682	753	103	763	781	754	15317				
792	57	742	7748	783	105	793	793	784	15419				
822	57	766	7811	813	106	823	804	814	15512				
852	57	790	7871	843	107	853	815	844	15596				
882	57	815	7929	873	108	883	825	874	15675				
912	57	839	7986	903	109	913	835	904	15750				
942	57	863	8040	933	111	943	844	934	15820				
972	57	887	8093	963	112	974	853	965	15885				
1002	57	911	8145	993	113	1004	862	995	15946				
1032	57	935	8194	1023	115	1034	870	1025	16003				
1062	57	959	8242	1053	116	1065	878	1056	16055				
1092	57	984	8289	1083	117	1095	885	1086	16105				
1122	57	1008	8334	1113	118	1125	892	1116	16152				
1152	57	1032	8378	1143	119	1156	899	1147	16196				
1182	57	1056	8421	1173	120	1186	906	1177	16237				
1212	57	1080	8464	1203	121	1216	912	1207	16276				
1242	57	1104	8505	1233	122	1247	917	1238	16313				
1272	57	1128	8546	1263	123	1277	922	1268	16348				
1302	57	1153	8586	1293	125	1307	927	1298	16380				
1332	57	1177	8624	1323	126	1338	932	1329	16412				
1362	57	1201	8662	1353	127	1368	936	1359	16442				
1392	57	1225	8699	1383	128	1398	941	1389	16471				
1422	57	1249	8736	1413	129	1429	945	1420	16500				

Note 1: The time given for each sampling area is the average of the elapsed times for the three swatches tested per sampling area.

Note 2: The avg. time is the sum of the times given for each sampling area divided by the number of sampling areas.

Note 3: Weighted average $M_f = 0.5$(Suit Matl M_f) + 0.15(Suit Seam M_f) + 0.15(Hood Matl M_f) + 0.1(Crotch Matl M_f) + 0.05(Boot Seam M_f) + 0.05(Zipper Seam M_f).

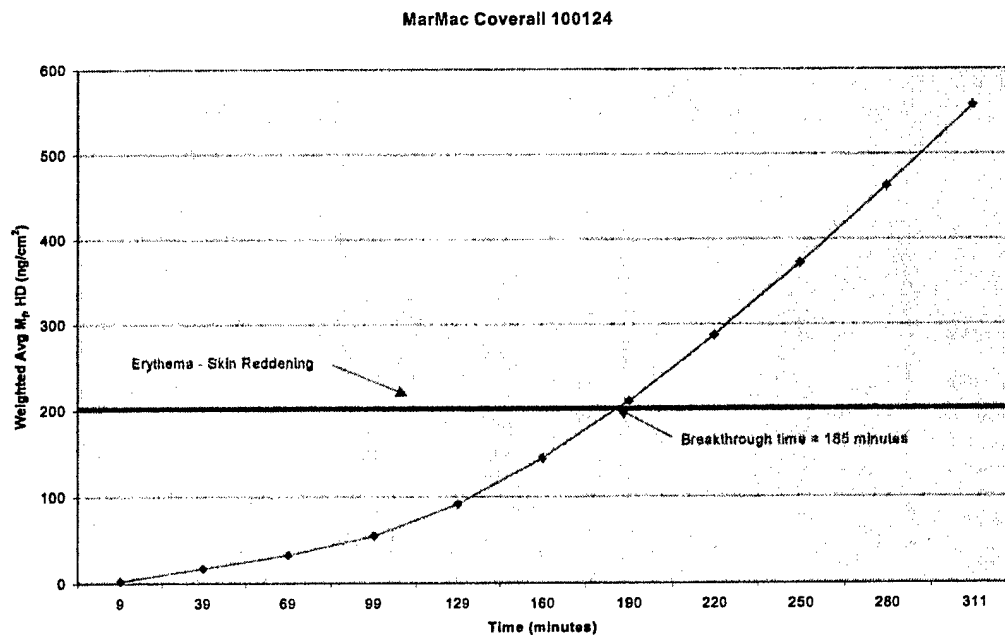Note 4: Sampling for the zipper seam was ended prematurely due to equipment failure.

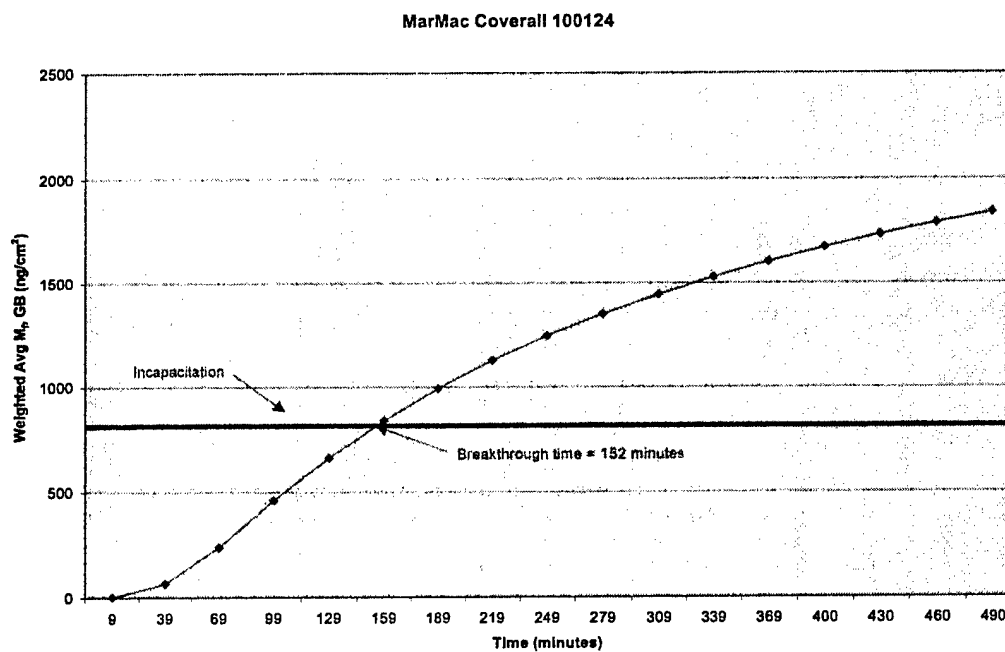**Figure E - 2. Mar Mac 100124 - Weighted Average HD Permeation**

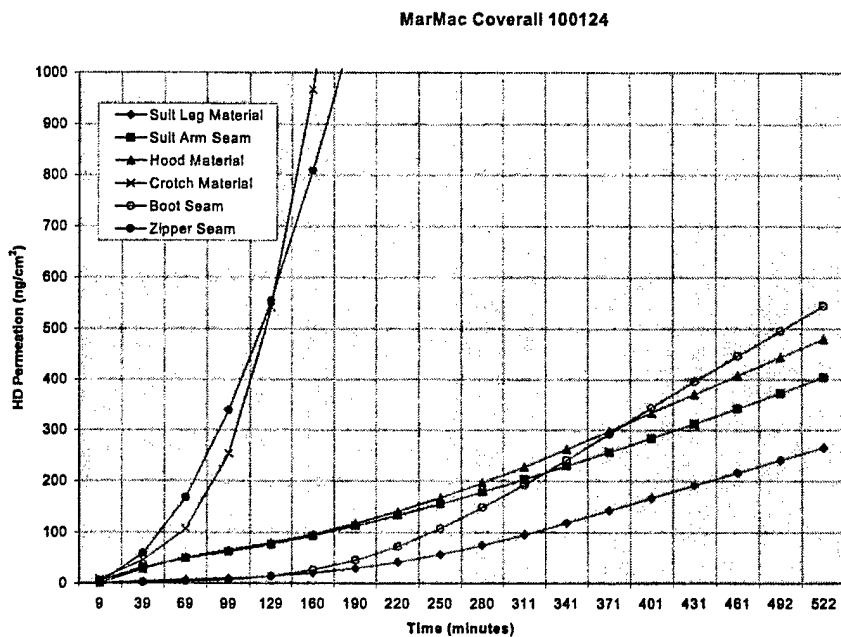**Figure E - 3. Mar Mac 100124 - Weighted Average GB Permeation**

MarMac Coverall 100124

Figure E - 4. Mar Mac 100124 - HD Permeation By Sampling Area
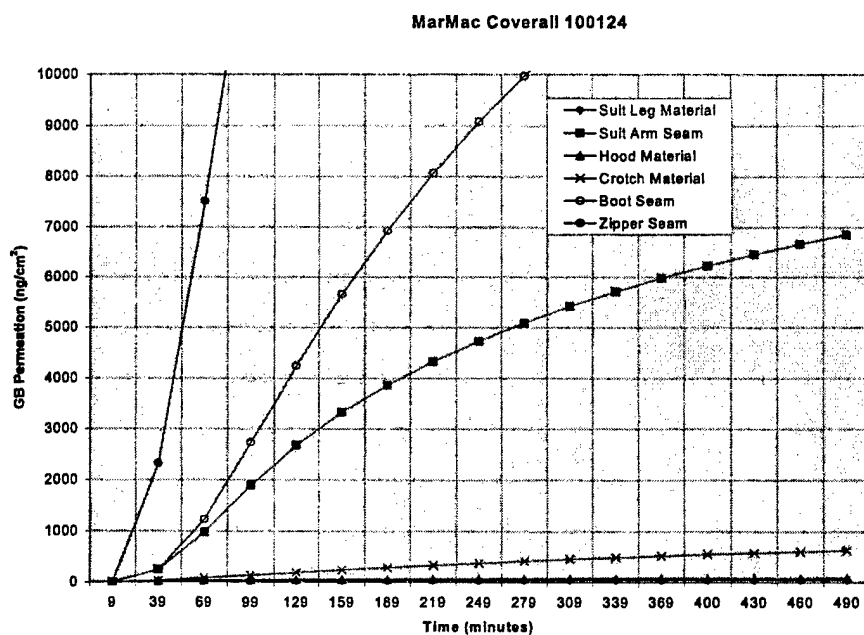
MarMac Coverall 100124

Figure E - 5. Mar Mac 100124 - GB Permeation By Sampling Area

Table E - 3. Mar Mac 100124 - System Test (Aerosol Simulant) Results

PF	Visor Region and Upper Arm, Combined					
	Pre-Operational Exercises			Operational Exercises		
	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent	Frequency	Cumulative Rate, Percent	Cumulative Pass Rate, Percent
0	0	.00	100.00	0	.00	100.00
2	13	54.17	45.83	14	58.33	41.67
5	10	95.83	4.17	9	95.83	4.17
10	1	100.00	.00	1	100.00	.00
50	0	100.00	.00	0	100.00	.00
100	0	100.00	.00	0	100.00	.00
150	0	100.00	.00	0	100.00	.00
500	0	100.00	.00	0	100.00	.00
1000	0	100.00	.00	0	100.00	.00
1667	0	100.00	.00	0	100.00	.00
2000	0	100.00	.00	0	100.00	.00
5000	0	100.00	.00	0	100.00	.00
6667	0	100.00	.00	0	100.00	.00
10000	0	100.00	.00	0	100.00	.00
20000	0	100.00	.00	0	100.00	.00
50000	0	100.00	.00	0	100.00	.00
100000	0	100.00	.00	0	100.00	.00
No. of Trials	24			24		

Table E - 4. Mar Mac 100124 - Overall Test Results

Physiologically-derived breakthrough time (minutes)					
Incapaci-tation	Erythema	Aerosol PF Pass Rate (%) at PF Equal to:			Exercise Phase
GB	HD	2	5	10	
152	185	46	4	0	Pre-Operational
		42	4	0	Operational

Appendix F

Overall Test Results
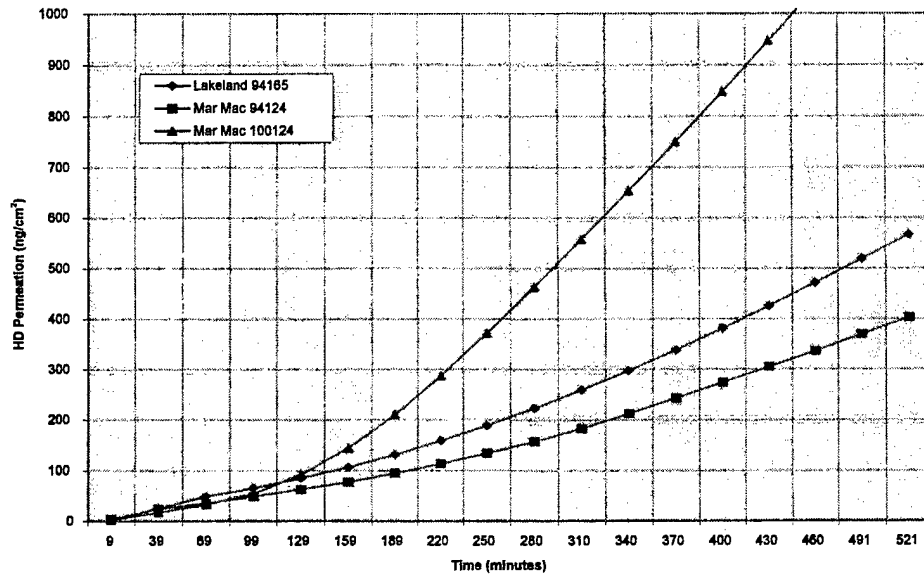
Summary of HD Permeation Results

Figure F - 1. Weighted Average HD Permeation
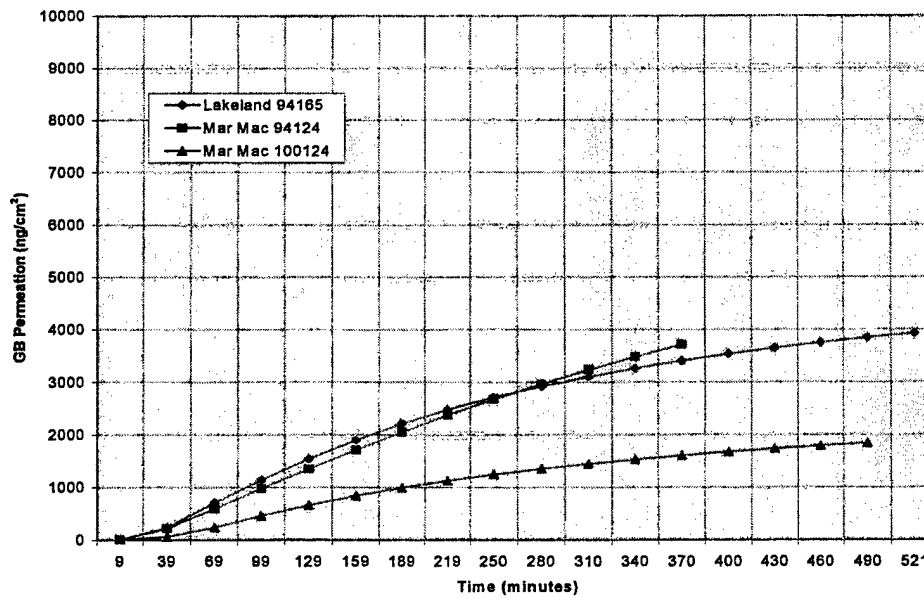
Summary of GB Permeation Results

Figure F - 2. Weighted Average GB Permeation

Table F - 1. Summary of Overall Results for all Level B Suits

Test Item	Physiologically-derived breakthrough time (minutes)		Aerosol PF Pass Rate (%) at PF Equal to:			Exercise Phase
	Incapacitation	Erythema				
	GB	HD	2	5	10	
Lakeland Coverall, Style 94165	76	260	46	8	0	Pre-Operational
			46	8	0	Operational
Mar Mac Coverall, Model 94124	86	329	50	25	0	Pre-Operational
			50	13	0	Operational
Mar Mac Coverall, Model 100124	152	185	46	4	0	Pre-Operational
			42	4	0	Operational

The swatch testing indicates at least a moderate level of protection from permeation of GB and HD, but the aerosol test results suggest leakage through poorly sealed closures. This phenomenon has been noted for other suits, closures are a major issue. Aerosol testing evaluates penetration through openings and through materials that are permeable. Vapor testing (swatch) can evaluate impermeable materials.